The Ages, Masses, Evolution and Kinematics of Mira Variables

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Abstract

Evidence on the ages and masses of Mira variables is reviewed. Period increases with increasing initial mass. Miras of $\log P \sim 3.0$ have initial masses near $4M_\odot$. It is suggested that the apparent gap in the LMC Mira PL relation at about this period may be due to the onset of hot bottom burning and that this adds ~ 15 to 20 percent to the stellar energy production. Shorter period HBB stars are probably overtone pulsators. T Lep may be an example of cool bottom processing.

1 Introduction

Mira variables are at the final stage of AGB star evolution and their observation is of particular importance since theory has so far been unable to make firm quantitative predictions regarding several aspects of this phase. They are also the brightest objects (particularly in the infrared) in old and intermediate age populations. They are thus important for the study of the distribution and kinematics of old and intermediate populations in our own and other galaxies. Several examples of progress in both these areas using the Japanese-South African IRSF-Sirius combination have been given at this meeting (e.g. [1] [2] [3]). The aim of the present paper is to summarize some of the relevant observational data on the ages, masses, state of evolution and kinematics of these objects and to draw tentative conclusions which further work may confirm or falsify.

2 The PL Relation and the Miras above it

Miras in the LMC are found to define a narrow period-luminosty (PL) relation at K extending from $\log P \sim 2.1$ to 2.6 [4]. Oxygen-rich (O-Miras) and carbon-rich (C-Miras) Miras lie together on this relation. A similar relation holds in M_{bol} (see e.g. [5]). In this case there may be a slightly different relation for O-Miras than for C-Miras. However, in the range $\log P \sim 2.6$ to 2.8, the LMC Miras lie systematically above a linear extrapolation of the PL in either K or M_{bol}. The VERA parallax of UX Cyg shows that such stars exist in our own Galaxy [6] [7]. In 1989 [4] the reason for these "above-PL" stars was not known and it was suggested that they might evolve into OH/IR stars at much longer

periods (i.e. that they were not yet, like "true" Miras, at the end of their AGB evolution). Alternatively, Hughes and Wood [8], who found more objects in the $\log P \sim 2.6$ to 2.8 range, suggested that there was a real steepening of the PL slope at about $\log P = 2.6$. However, all these early studies relied on optically selected samples. The matter was very considerably clarified by Whitelock et al. [9]. They studied objects in the LMC obscured by circumstellar shells and found Miras with periods in the range $\log P \sim 2.6$ to 3.2 which lay on an extrapolation of the M_{bol} PL relation at shorter periods. They also found that Miras in which lithium lines had been detected [10] and which are thought to be Hot Bottom Burning (HBB) stars lay in the above-PL group, suggesting that all the above-PL Miras might be HBB stars. HBB is believed to be an important process in the late evolution of stars of mass above about 3 or $4M_\odot$. Such stars are expected to dredge up and eject helium-rich material. This is of current relevance for our understanding of globular cluster evolution. If an earlier generation of intermediate mass AGB stars in a cluster enriched the interstellar medium of the cluster in helium, this might explain the helium-rich sequences found in some clusters. The matter remains controversial and Renzini [11], who has summarized the present position, points out that much depends on the details of the way HBB operates and these can only be found observationally. It is evident therefore that identifying and studying HBB Miras is a matter of particular interest.

3   The ages and initial masses of Miras

Galactic globular clusters contain O-Mira variables in the range $\log P \sim 2.0 - 2.5$. These lie on the PL relation [12]. There is also a rather clear period-metallicity relation [13] [1]. Evidently these Miras all have low initial masses. It is possible that there might be a general (slight) increase of initial mass with [Fe/H]. Whether this is so or not depends both on the adopted stellar models and the relative ages of clusters of different metallicity and thus remains uncertain. Since the change of mass with period for the cluster stars must in any case be small, the range in period must reflect an increase in stellar radius caused by increasing [Fe/H]. It is well known that there is a dependence of O-Mira kinematics on their periods [15]. This allows one to estimate ages as a function of period by comparison of O-Mira velocity dispersions [16] with relations between age and velocity dispersion for stars in the solar neighbourhood [17]. The shortest period group ($\log P \sim 2.3$) are evidently globular-cluster-like and will have initial masses of $< 1M_\odot$. The bulk of the Galactic Miras have $\log P \sim 2.5$ and are ~ 7Gyr old. The group with $\log P \sim 2.65$ (which might contain some above-PL stars) is ~ 3Gyr old. Evidently these stars are of low initial masses though this increases with increasing period. Assuming that the OH/IR Mira with $\log P = 3.107$ is a member of the LMC cluster HS327 [18], its initial mass is about $4M_\odot$. Note that as discussed earlier [16] [19] the O-Miras allow one to distinguish between two alternative interpretations of Galactic kinematics.

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[1]There may be complications to this in the case of clusters showing the second parameter effect (e.g. NGC 6441) [14].

Galactic C-Miras are mostly confined to the longer periods. Their kinematics at a mean $\log P = 2.717$ [16] indicates a mean age of ~ 1.8Gyr and an initial mass of $\sim 1.8 M_\odot$. There is an indication that, as for O-Miras, period increases with decreasing age. At a given period the age of a C-Mira may be slightly less than that of an O-Mira, but this is uncertain. The discovery [20] of three clusters in the Magellanic Clouds containing C-Miras was a major breakthrough in age/mass derivation. These stars which lie on the PL also have a mean age ~ 1.8Gyr (mean $\log P = 2.689$). Van Loon et al.[21] suggest that a C-Mira with $\log P = 2.833$ belongs to the LMC cluster KMHK with an age of ~ 1.0 Gyr and an initial mass of $\sim 2.2 M_\odot$, consistent with the gradual increase of initial mass as one moves up the PL.

4   Hot Bottom Burning Stars

Taking together the results for samples of LMC Miras selected optically [4] and from infrared properties [9] one finds the following for stars on or near the PL: (1) Between $\log P \sim 2.1$ and 2.6 there is a mixture of O and C-Miras. (2) Between $\log P \sim 2.6$ and 3.0 the stars are nearly all C- Miras. There is only one O-Mira in this range and it is at the long period end ($\log P = 2.95$). (3) There seems to be a rather conspicuous gap with no Miras between $\log P = 2.97$ and 3.03. (4) At $\log P > 3.0$ only O-Miras (including OH/IR Miras) have been observed. A similar situation exists in Our Galaxy where there are no C-Miras with $\log P > 3.0$ if one excepts one dubious case with $\log P = 3.02$. The period distribution of Galactic O-Miras (OH/IR stars) extends to longer than $\log P = 3.3$.

The above results indicate a rather sharp change in the distribution and composition of stars along the PL at $\log P \sim 3.0$. The discussion of the previous section also leads to the conclusion that at this period the Miras originate from stars of about 3 or $4 M_\odot$. This is the approximate mass range above which HBB is expected to start. Clearly if HBB does begin to operate at the mass of $\log P = 3.0$ Miras it will explain the sudden change from essentially all C-Miras at slightly shorter periods to all O-Miras at longer periods (and higher masses). HBB adds an extra energy source to the star. At least to a first approximation we would expect this to lead to an expansion of the star and hence to a longer pulsation period. If such is the case then the gap just mentioned leads to a measure of the extra energy produced. It is about 15 to 20 percent of the total stellar energy production.

If the stars with $\log P > 3.0$ are HBB stars (together perhaps with some post-HBB stars), how do we explain the above-PL stars, some with lithium, which are found at $\log P \geq 2.7$? The most likely solution is that these stars are overtone pulsators which have already started HBB and will evolve into O-Miras with $\log P \geq 3.0$. A pointer in this direction is that one of these above-PL and lithium rich stars (IRAS 04496-6958)[9] is a possible member of a young cluster LMC cluster HS33 [22]. If it is a member, it has an age of about 200Myr and an initial mass of about $4 M_\odot$, much larger than Miras on the PL at this $\log P$ (2.86). The above-PL stars have relatively low amplitudes for their periods [9]

and humps on the rising branches of their light curves both in the optical and the infrared [23] [24]. Ita et al. [25] have a sequence (C') of Mira-like stars in their LMC $K - \log P$ plot which lies above and nearly parallel to the Mira sequence. If this were plotted in M_{bol} rather than K it seems likely that our above-PL stars would lie on an extrapolation of this sequence to longer periods.

Garciá-Hernández et al. [26] have examined a group of Galactic O-Miras for strong lithium. Many of those with $\log P \sim 2.6$ to 2.8 do show lithium which they attribute to HBB (note that the longest period star in their fig 17 is WX Sgr, a supergiant not a Mira). If these Miras are indeed HBB stars and belong with the above-PL stars then it hints that there are relatively few Galactic O-Miras on the PL in this period range. A situation which, we have seen, seems to apply in the LMC. Some caution is however necessary. Their shortest period lithium-rich star is T Lep with $\log P = 2.57$. A preliminary VERA parallax of the star reported at this meeting [27] places it on the PL. Thus it will be of too low a mass for HBB and some other explanation of its lithium content is require. A likely candidate is the cool bottom process [28].

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